P03: Project Cost, Schedule, and Risk

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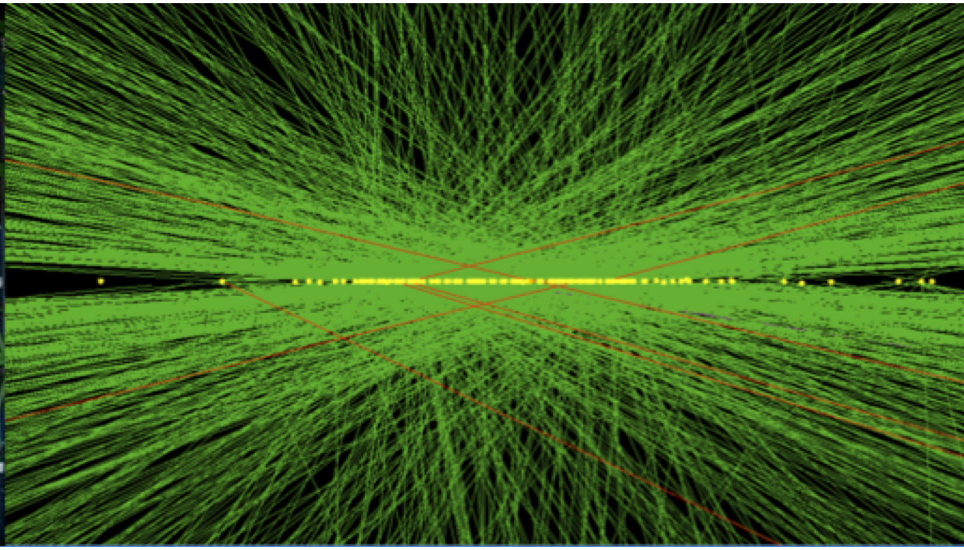
Fermilab Risk Manager

DOE CD-1 Review
Fermilab, 22nd October 2019



Outline

- **Cost** – Basis of Estimate (BoE)
- **Schedule** – Resource loaded schedule (RLS)
- **Risk** – Analysis and contingency
- **Summary**

Charge #3	Does the conceptual design report and supporting documentation adequately justify the stated cost range and project duration?
Charge #5	Does the proposed project team have adequate management experience, design skills and laboratory support to produce a credible technical, cost, and schedule baseline?
Charge #7	Is the documentation required by DOE O413.3b for CD-1 approval complete and in good order?

Lucas Taylor – Biographical sketch

Charge #5

Current roles

- **Associate Project Manager**, HL-LHC CMS Upgrades
  - Focusing on cost, schedule and risk
- **Fermilab Risk Manager** and **PIP-II Risk Manager**
  - Lab-wide Enterprise, Operations and Project Risk
  - Risk Register, MC analysis, workshops, reviews

Background

- **Deputy Project Manager**, CMS Phase 1 Upgrades
- **CMS management roles**
  - CMS Head of Communications
  - Collaboration Board Secretary
  - Member of CMS CB, MB, FB
  - CMS Computing & Offline: Deputy PM, Resource Manager, Technical Coordinator
- **Project Management Professional** (PMP) since 2005
- **PhD Particle Physicist** with CMS, L3, Pierre Auger Observatory, UA1

Cost Basis of Estimate (BoE)

Cost, schedule and risk documents

Charge #3, #7

WBS Dictionary	**CMS-doc-13213**
Key Assumptions	**CMS-doc-12919**
Labor rates w/ OH & fringe	**CMS-doc-13284**
Institute F&A rates	**CMS-doc-13272**

Cost
Estimation
- Elucidate project scope
- Solicit vendor information
- Estimate direct M&S costs
- Estimate costed labor
- Estimate scientific labor

Schedule
Development
- Define work activities
- Build schedule logic
- Load labor and M&S resources
- Optimize schedule
- Define milestones

Risk
Assessment
- Identify risks
- Estimate probability & impacts
- Plan risk mitigations & responses
- Perform stochastic MC analysis
  → cost & schedule contingency

Index of 52 BoEs in DocDB
incl. vendor information
https://go.usa.gov/xQ3JX

Primavera P6 Gantt	**CMS-doc-13245**
Milestones	**CMS-doc-13321**
Cost book	**CMS-doc-13215**

Risk Register	**CMS-doc-13480**
Risk Analysis	**CMS-doc-13481**

Updates since the DOE IPR (June 2018)

- Timing Layer bottom-up cost estimate and RLS → Charge
- Aligned project schedule to latest iCMS schedule → Charge
- Updated resource estimates (vendor quotes, labor estimates)
- Updated all resource rates in BoEs, P6, Cobra, risk analysis
  - Fully-burdened labor rates for institutes → CMS-doc-13284
  - Institute F&A indirect rates → CMS-doc-13272
  - Escalation rates for M&S and labor → CMS-doc-13481
  - Foreign exchange rates → CMS-doc-13481
- Updated RLS to reflect progress → recovered contingency
- Reviewed and updated all risks and added new MTD risks
- Scrubbed RLS to fit funding guidance of $162.05M (was $165M at IPR, June 2018)
- Identified $5.11M of new downscope options → Charge

Cost Basis of Estimate (BoE)

"Key Assumptions"
CMS-doc-12919

- Costs are estimated bottom-up by L2s, L3s, CAMs based on actual costs, vendor quotes and labor estimates from recent work or Phase 1

Charge #3

- BoEs describe the full work scope, key quantities, and cost estimates with supporting documents (e.g. vendor quotes), for the following
  - **M&S $:** Hardware, travel, COLA, teaching buyouts, shipping
  - **Labor hours:** Technical labor (costed & scientific) & project office

BoE index: https://go.usa.gov/xQ3JX

- Costs were reviewed and scrubbed (value engineering)
- BoEs serve as input to build P6 resource-loaded schedule
  - P6 applies the institute indirect costs, labor rates and escalation

M&S Costs

"Key Assumptions"
CMS-doc-12919

$$\text{M\&S (\$)} = \sum_{\substack{\text{Sum over}\\ \text{activities}}} \text{Direct M\&S cost (\$)} \times \left(1 + \text{Indirect rate (\%)}\right) \times \left(1 + \text{Escalation per yr (\%)}\right)^{\text{No. years}}$$

- **Direct M&S** costs expressed in base year $ (e.g. FY19$)
  - Standard guidance for travel and cost of living at CERN → CMS-doc-13353
  - Foreign costs expressed in $ using standard exchange rates

  Risk RU-402-1-01-D: *Future exchange rates ($36.0M in foreign costs)*

- **Indirect facilities and administration ("F&A") rates** → CMS-doc-13272
  - Collected from all institutes and applied in P6 / Cobra

  Risk RU-402-1-03-D: *Future indirect rates (esp. $58.6M costs at Fermilab)*

- **Escalation** is applied in P6 / Cobra to allow for inflation → CMS-doc-13481
  - OMB guidance, US Bureau of Labor Statistics, Office of Fermilab CFO
  - 2.0% for M&S and 3.2% for Labor

  Risk RU-402-1-02-D: *Uncertainty in future escalation rates*

Labor Costs

"Key Assumptions"
CMS-doc-12919

$$\text{Labor (\$)} = \sum_{\text{Sum over activities}} \text{Number of hours} \times \text{Hourly rate w/ fringe (\$)} \times \left(1 + \text{Indirect rate (\%)}\right) \times \left(1 + \text{Escalation per yr (\%)}\right)^{\text{No. years}}$$

- **Number of labor hours** is assigned per P6 activity, per labor resource – by institute, job function and level
  - ***Risks RT-402-n-90-D (n=1,2,4,6,8):*** *Key personnel need to be replaced*
- **Hourly rates** (fully burdened) per labor resource were obtained from institutes and entered into P6 and Cobra → CMS-doc-13284
- Contributed (scientific) labor needs are also included in P6
  - Faculty, physics postdocs and graduate students
  - ***Risks RT-402-n-91-D (n=2,4,6,8):*** *Contributed labor is unavailable*

Cost Estimate Uncertainty (EU)

"Key Assumptions"
CMS-doc-12919

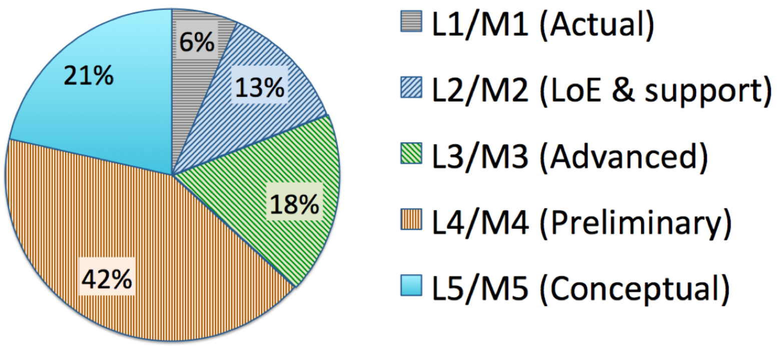
- Cost estimates have intrinsic uncertainty due to design maturity, vendor prices, labor estimates
- Estimate uncertainty is estimated per activity as % of base cost
  - Follow guidance from Fermilab Office of Project Support Services
- Estimate uncertainty = **$27.3M** (25.6% of base cost to go*)

IPR (June 2018): EU= $34.6M (29.8% of c.t.g.)

* Not including risk-based contingency (see later slides)

Estimate Type	Estimate Maturity Code	Mean estimate uncertainty Fermilab OPSS guidance (% of base cost)
Actual cost / Existing PO	L1/M1	0
Level of effort / Support / Oversight	L2/M2	0 – 20
Advanced	L3	10 – 25
	M3	10 – 20
Preliminary	L4	25 – 40
	M4	20 – 40
Conceptual	L5/M5	40 – 60
Pre-conceptual – Common work	L6/M6	60 – 80
Pre-conceptual – Uncommon work / Rough estimate	L7/M7	80 – 100
Beyond state of the art	L8/M8	>100

Cost-weighted estimate maturity
HL-LHC CMS Detector Upgrades Project



Project Cost Drivers*

CMS Driver	Labor (FTE-yrs)	Labor BAC (M$)	M&S BAC (M$)	Total BAC * (M$)
OT.5 - Produce and test modules	57.3	8.6	1.5	10.2
CE.3 - Si sensors purchase (M&S)	0.0	0.0	7.7	7.7
PM - Project Controls and Finance	19.2	6.6	0.3	6.9
PM - CMS Common Fund (DOE)	0.0	0.0	5.8	5.8
OT.3 - Procure Sensors	0.0	0.0	4.5	4.5
PM - Project Management	10.0	3.9	0.0	3.9
OT.5 - Module mechanics	2.2	0.3	3.0	3.3
TL - ETL ASIC Development	12.5	1.8	1.3	3.2
OT.5 - Procure hybrids	0.0	0.0	3.2	3.2
OT.5 - Establish / maintain module assembly site	5.0	0.7	2.1	2.8
CE.7 - Concentrator ASIC (labor)	9.7	2.8	0.0	2.8
CE.5 - Silicon motherboard (M&S)	0.0	0.0	2.5	2.5
OT.4 - MaPSA purchase and testing	2.3	0.1	2.3	2.4
CE.5 - Cassette assembly and testing (labor)	15.9	2.4	0.1	2.4
OT.6 - Plank and Ring mechanics	11.2	1.7	0.6	2.4

PM = Project Management   OT = Outer Tracker   CE = Calorimeter Endcap   TD = Trigger and DAQ   TL = Timing Layer

* Some subjectivity in how items are grouped

* BAC = Budget at Completion (=direct + indirect + escalation)

Cost Summary

- **Total Cost = $162.03M** (= Base Cost + Estimate Uncertainty + Risk)

HL-LHC CMS Upgrades Project	M&S			Labor					Risk	Total (M$)
	Base Cost (M$)	EU (M$)	M&S (M$)	Contrib (FTE-years)	Costed (FTE-years)	Base Cost (M$)	EU (M$)	Labor (M$)	Risk Contin-gency (M$)	
402.1 PROJECT MANAGEMENT	6.92	0.63	7.55	1.8	34.0	12.36	0.99	13.35	0.00	20.90
402.2 OUTER TRACKER	23.84	6.06	29.90	100.6	112.6	19.03	3.83	22.86	3.58	56.34
402.4 ENDCAP CALORIMETER	23.62	6.03	29.65	83.5	104.6	17.06	4.11	21.17	3.44	54.25
402.6 TRIGGER AND DAQ	4.45	1.37	5.82	30.3	30.5	4.63	1.07	5.70	1.11	12.63
402.8 TIMING LAYER	7.85	1.46	9.31	50.8	37.5	4.86	1.77	6.64	1.95	17.90
Total Cost	66.69	15.54	82.23	266.9	319.3	57.95	11.77	69.72	10.07	162.03
Funding Guidance										162.05

2019-10-07---cost-rollup---CD1-v2.xlsx
Last updated: Lucas Taylor 2019-10-15

Note: Base Cost = Direct + Indirect + Escalation

Cost Summary – KPPs

CMS-doc-13215
CMS-doc-13481

- **Threshold KPPs** = Main construction deliverables ($147.19M)
- **Objective KPPs** = Technical scope options ($5.11M)
  + Integration & Commissioning ($9.72M)

HL-LHC CMS Upgrades Project	T-KPP (M$)	O-KPP (M$)	Total (M$)
	Total = Threshold KPPs + Objective KPPs		
402.1 PROJECT MANAGEMENT	19.24	1.65	20.90
402.2 OUTER TRACKER	52.36	3.98	56.34
402.4 ENDCAP CALORIMETER	48.95	5.30	54.25
402.6 TRIGGER AND DAQ	10.16	2.47	12.63
402.8 TIMING LAYER	16.47	1.43	17.90
Total Cost	147.19	14.84	162.03
Funding Guidance			162.05

2019-10-15---cost-rollup---CD1-v2.xlsx
Last updated: Lucas Taylor 2019-10-15

Includes all the costs for the threshold and objective KPP scope

Cost Summary – Contingency

CMS-doc-13215
CMS-doc-13481

- **Contingency** (= Estimate Uncertainty + Risk) **= 35.1%** of cost-to-go

IPR (June 2018): 38.8% of c.t.g.

HL-LHC CMS Upgrades Project	Total = Work done + Cost to go + Contingency				
	Work done (M$)	Cost to go (M$)	Contingency = EU + risk (M$)	Contingency = EU + risk (% CTG)	Total (M$)
402.1 PROJECT MANAGEMENT	3.13	16.15	1.61	10.0%	20.90
402.2 OUTER TRACKER	7.86	35.01	13.47	38.5%	56.34
402.4 ENDCAP CALORIMETER	5.28	35.39	13.58	38.4%	54.25
402.6 TRIGGER AND DAQ	1.30	7.78	3.54	45.5%	12.63
402.8 TIMING LAYER	0.54	12.18	5.18	42.5%	17.90
Total Cost	18.12	106.52	37.39	35.1%	162.03
Funding Guidance					162.05

2019-10-15---cost-rollup---CD1-v2.xlsx
Last updated: Lucas Taylor 2019-10-15

- **Scope options = $5.11M** (= **$3.86M** base cost + **$1.25M** EU)
- If this base cost were used as contingency: **Contingency = 40.2%** of cost-to-go

→ Charge

Schedule

Resource Loaded Schedule (RLS)

CMS-doc-13321
CMS-doc-13245

- RLS is built in Oracle's ***Primavera P6***, with strong support from the Fermilab Office of Project Support Services

Charge #5

- **RLS has 4692 resource-loaded activities**

  Activities cover: technical tasks, procurement, QA/QC, shipping, project mgmt. and controls, finance, administration, travel, COLA

  - **Average Activity base cost = $26.6k**
  - **Average Activity duration = 2.4 months** (not counting LoE/support)

- **284 iCMS external milestones** – not all influence US scope

- **785 technical milestones** (9/month) to track future progress

Milestones

CMS-doc-13321

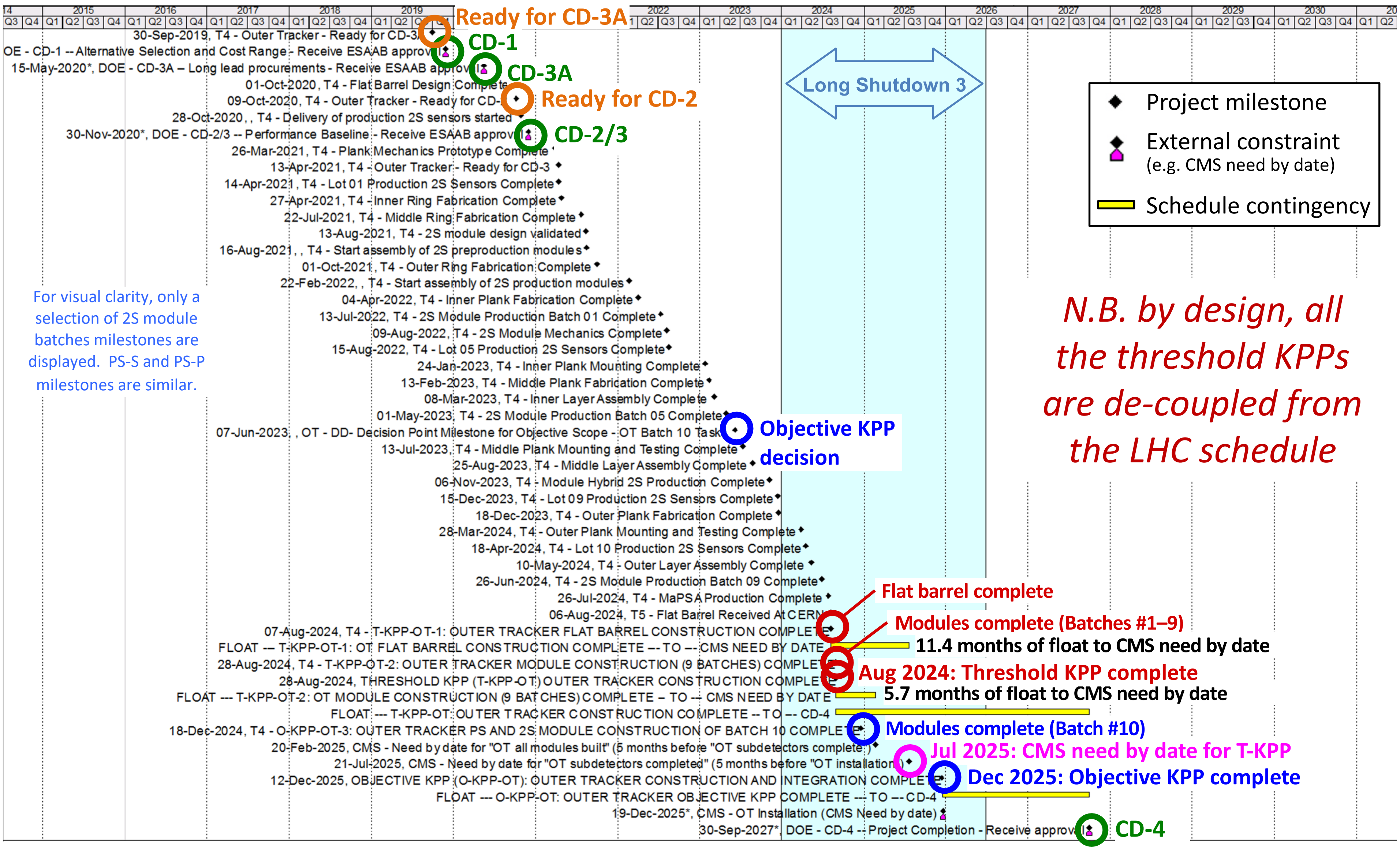
→ Charge

- High level reporting milestones have 3-6 months of schedule contingency relative to their technically-driven (T4) predecessors
  - **T2** milestones (×**69**) – owned by DOE and Federal Project Director
  - **T3** milestones (×**137**) – owned by Fermilab
- Technically-driven milestones are used to track technical progress for all work done (by both costed and scientific labor)
  - **T4** milestones (×**273**) – owned by Project Manager
  - **T5** milestones (×**511**) – owned by L2 Manager or CAM
- External constraint milestones are used to align to the iCMS schedule
  1. ***External things that are needed by the Project*** (e.g. funding, iCMS chips)
     - These are ***predecessors*** (pre-requisites) to subsequent project work
  2. ***Deliverables of the Project that are needed by iCMS***
     - These are ***successors*** to the project work that produces the deliverable
     - Project maintains schedule contingency before the iCMS “need by” milestones

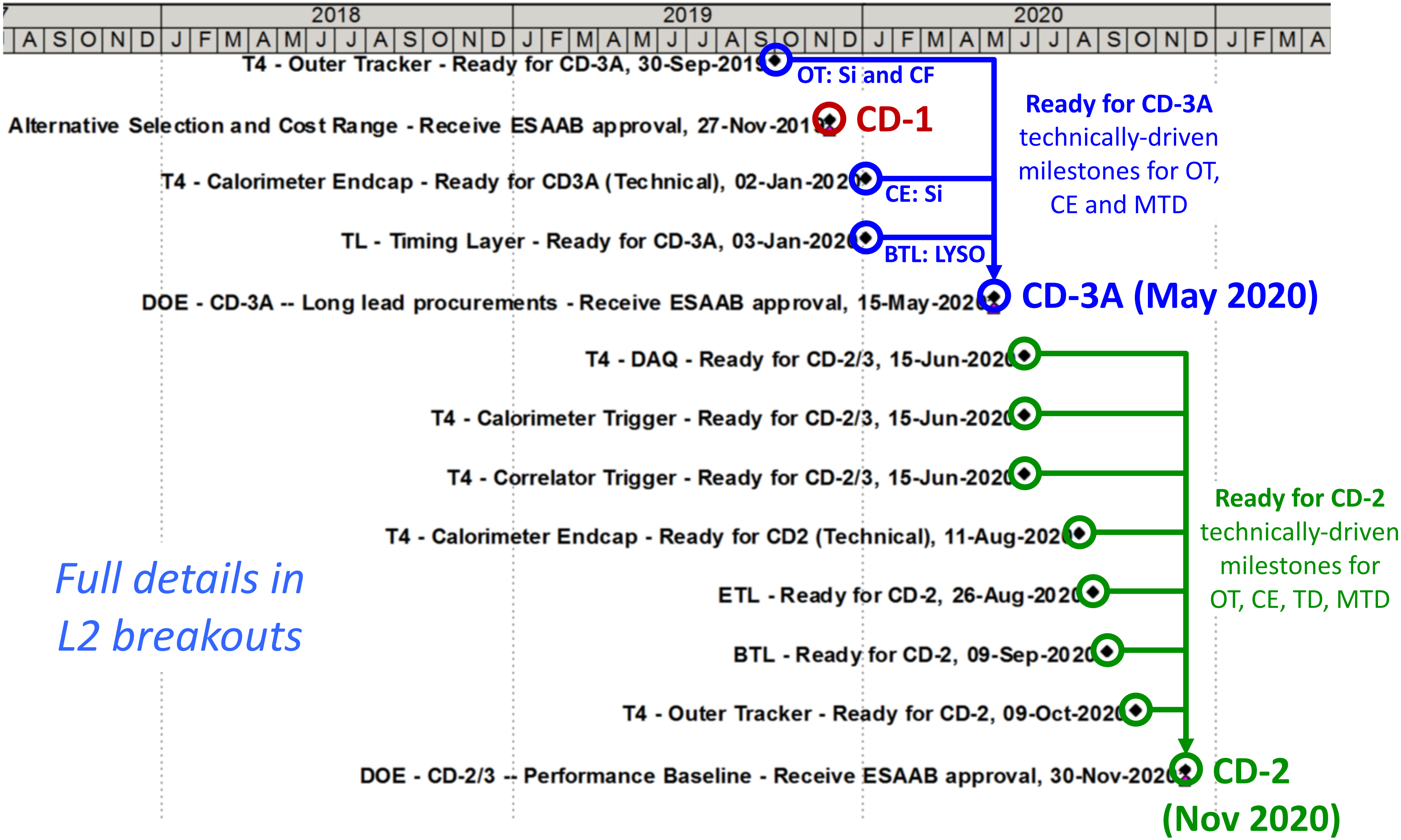
Milestones

Example: Outer Tracker high-level milestones

CMS-doc-13321
CMS-doc-13245



CD-3A and CD-2 readiness milestones



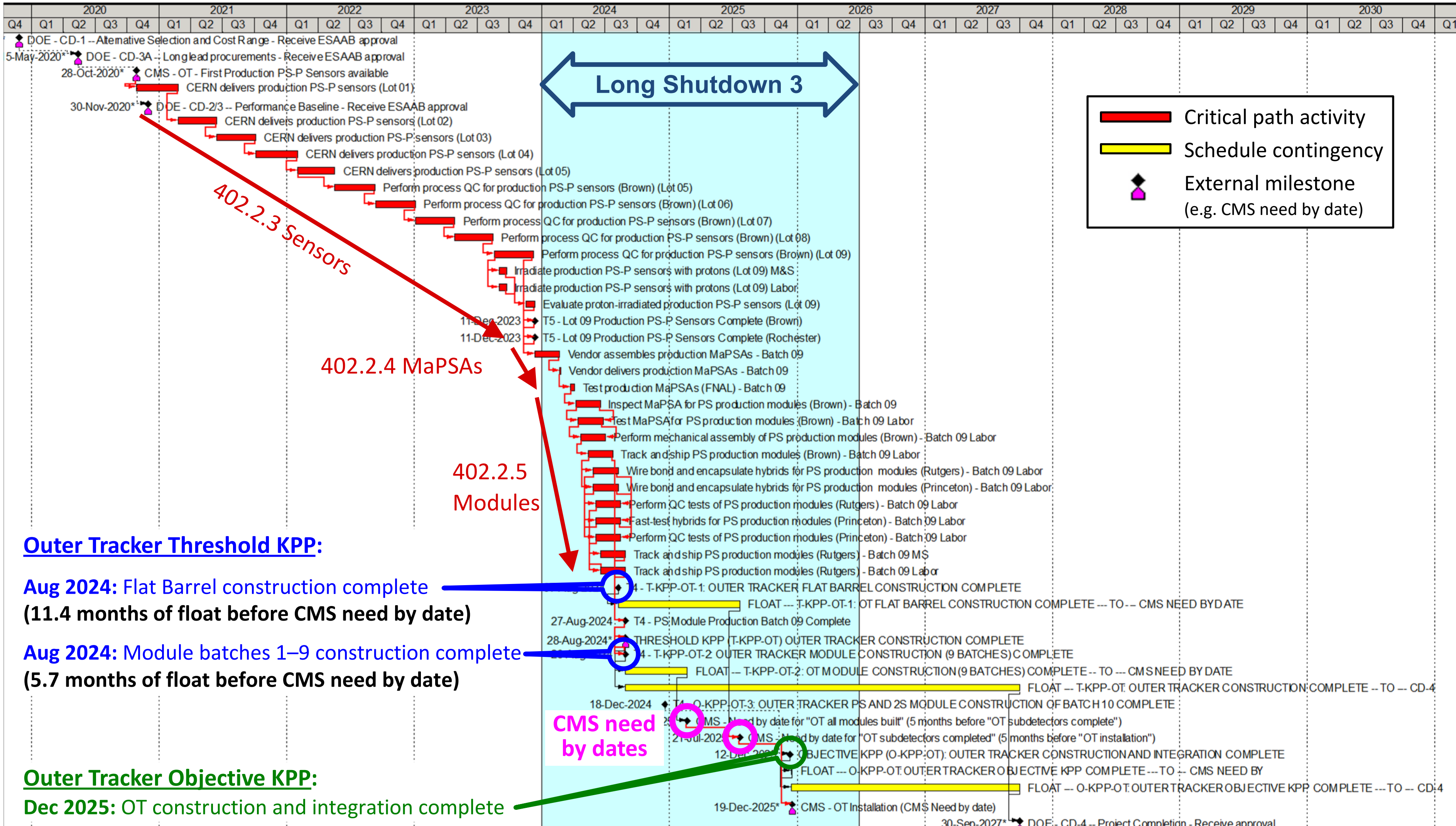
Full details in L2 breakouts

Critical Path and Schedule Contingency

- RLS is technically-driven
- RLS respects CMS/LHC schedule and DOE profile
- RLS factorizes into seven almost independent L2/L3 areas, with distinct critical paths → less schedule risk
  - (1) Outer Tracker, (2) Calorimeter Endcap, (3) Calorimeter Trigger, (4) Correlator Trigger, and (5) DAQ, (6) Barrel Timing Layer and (7) Endcap Timing Layer
- To ensure we can deliver to CMS on time, we include schedule contingency between
  1. **Threshold KPP early finish date** and the corresponding
  2. **CMS “needs by” date**

Critical Path and Schedule Contingency

Example: 402.2 Outer Tracker



Outer Tracker Threshold KPP:

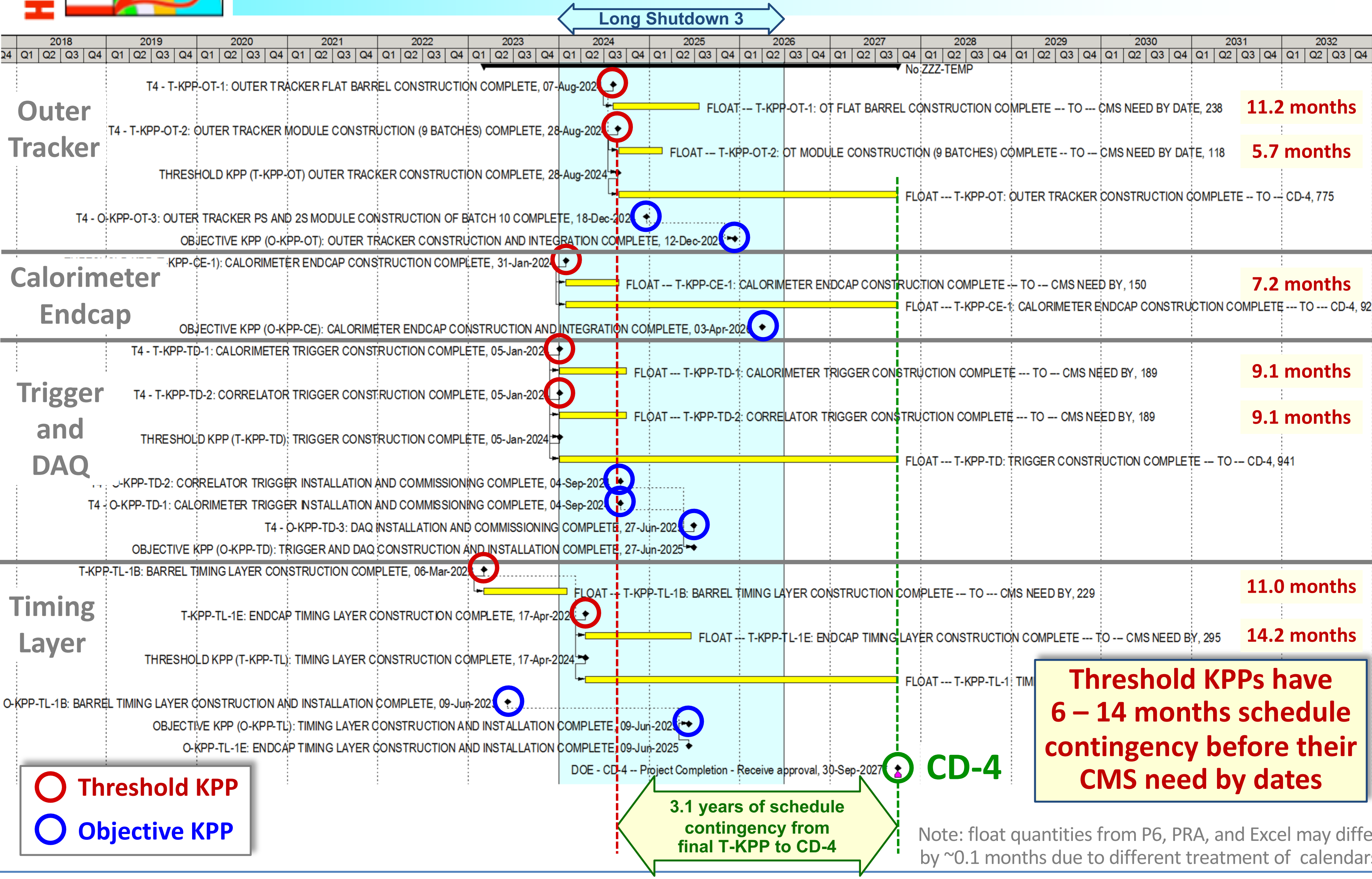
Aug 2024: Flat Barrel construction complete
(11.4 months of float before CMS need by date)

Aug 2024: Module batches 1–9 construction complete
(5.7 months of float before CMS need by date)

Outer Tracker Objective KPP:
Dec 2025: OT construction and integration complete

Schedule Contingency

CMS-doc-13237



Risk Analysis and Contingency

Risk Management

- **Risk management** addresses the effects of uncertainties on objectives
  - **70 Threats:** **negative** risks – minimize probability and impacts
  - **2 Opportunities:** **positive** risks – maximize probability and impacts
  - **5 Uncertainties:** **positive or negative** – need to manage them
- **We use Fermilab's OPSS-supported risk process & tools**
  - These are based on PMI's PMBOK and DOE 413.3b)
  - Risk issues discussed weekly as required; full risk board meeting every 2-3 months

Charge #5

- **Risk identification** is carried out by CAMs, SMEs, L2s, PMs …
  - Risk workshops, brainstorming, WBS and RBS review
  - Estimate risk probability and cost and schedule impacts
- **Risk mitigations** are pre-emptive actions in our base plans
  - R&D, pre-production, QA/QC, multiple vendors, redundant facilities…
- **Risk response plans** use contingency to cope with residual risk
  - ***In extremis***: don't complete all the objective KPP scope

→ **CMS-doc-13237**

- **Risk MC analysis** aggregates the consequences of all risks
  - Including costs from **standing army** and **escalation due to delays**

Risk updates since DOE IPR (June 2018)

The IPR was concerned that technical risk may be under-estimated, so we systematically re-assessed all risks

→ Charge

- 3 workshops to review OT, CE, and TD risks, with external experts
  - **402.2 Outer Tracker:** New: OT Wire bonding problems, flat barrel damage; Updated: OT C-foam, sensor quality, QC sites, mechanics vendor; Standing army costs for module assembly
  - **402.4 Calorimeter Endcap:** New: Need to accelerate production, Si motherboard complexity. Retired: Cheaper p-on-n Si wafers; Non-delivery of Si sensors
  - **402.6 Trigger and DAQ:** New: Inadequate DAQ storage manager I/O performance
- MTD internal risk workshop identified and analyzed 30 MTD risks
- 2 workshops with external experts reviewed / updated MTD risks
- Review Fermilab Risk Breakdown Structure for missing risks (→ extra slide)
- Updated project wide risks
  - A year has passed, so exchange rate, escalation, and OH risks are all diminished. Transferred key personnel and contributed labor risks to L2.

Risk Register

- Risks are managed in Fermilab's web-based Risk Register

Example risk:

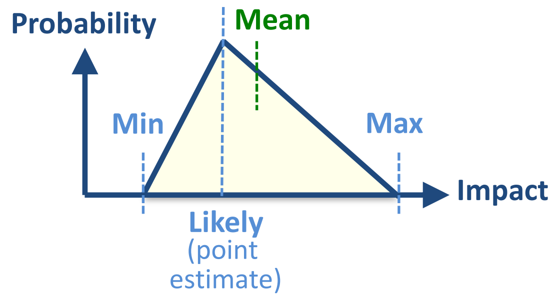
Charge #5

RU-402-1-01-D PM - Foreign exchange rates are uncertain (DOE)

Risk Rank:	3 (High) **Scores:** Probability : 5 (VH) ; Cost: 3 (H) Schedule: 0 (N))	**Risk Status:**	Open
Summary:	Future exchange rates are more or less favorable than the canonical value in the baseline plan resulting in a change in the cost to the project.		
Risk Type:	Uncertainty	**Owner:**	Steven C. Nahn
WBS:	402.1 PM - Project Management (DOE)	**Risk Area:**	External Risk / Market
Probability (P):	100%	**Technical Impact:**	0 (N) - negligible technical impact
Cost Impact:	PDF = 3-point - triangular Minimum = -6,600 k$ Most likely = 1,120 k$ Maximum = 9,420 k$ Mean = 1,313.3 k$ P * <Impact> = 1,313.0 k$	**Schedule Impact:**	PDF = 1-point - single value Minimum = N/A Most likely = 0.0 months Maximum = N/A Mean = 0 months P * <Impact> = 0 months
Basis of Estimate:	The cost impact parameters are the result of a detailed scenario analysis. Historical exchange rate data were used to replay typical rate variations (scenarios) and hence model potential future changes (typical percentage changes from quarter to quarter -- not absolute rates), as described inCMS-doc-13481 and calculated in CMS-doc-11825. The risk uncertainty is applied to the amount of foreign costs per fiscal year (determined from P6) throughout the project allowing for the fact that the uncertainty increases further into the future.		
Cause or Trigger:		**Impacted Activities:**	
Start date:	1-Oct-2019	**End date:**	30-Jun-2026
Risk Mitigations:	The exchange rate uncertainty increases the further in the future the cost is incurred. Therefore the project will seek to advance foreign exchange transactions where possible and consistent with the availability of funds. For example, it may be possible to front-load the payment of the CMS common fund (in Swiss Francs) or procure silicon (in Yen) earlier than is absolutely needed (on technical grounds).		
Risk Responses:	If the cost impacts are acceptable the risk response is to use contingency to cover the increased costs. For extreme exchange rate changes that cannot be covered by contingency, work with the agencies to address the issue. In extremis, do not complete the objective KPPs if there are insufficient funds.		
More details:	CMS-doc-13481		

Risk Analysis

- CAMs estimate the probability and cost & schedule impacts
  - 1-point (single value)
  - 2-point (flat range)
  - 3-point (triangle function)
- Risks ranked using matrix
  - Probability vs. Impact
- Project has 77 open risks
  - **15 High rank** (FPD & PM)
  - **36 Medium** (PM & L2s)
  - **26 Low** (L2s & CAMs)



HL-LHC CMS Upgrades Risk Impact Scoring	Low Impact	Medium Impact	High Impact
Technical Impact	Somewhat sub-standard	Significantly sub-standard	Extremely sub-standard or KPP in jeopardy
Cost Impact	(0.1 – 0.3) M$	(0.3 – 1) M$	> 1 M$
Schedule Impact	(1 – 3) months	(3 – 6) months	> 6 months

Maximum value of all impacts (above) determines overall risk impact (below)

Risk ranking matrix (Probability vs. Impact)		Low Impact	Medium Impact	High Impact
Very High	64 - 100%	Medium Rank	High Rank	High Rank
High	39 - 64%	Medium Rank	High Rank	High Rank
Medium	21 - 39%	Low Rank	Medium Rank	High Rank
Low	9 - 21%	Low Rank	Medium Rank	Medium Rank
Very low	0 - 9%	Low Rank	Low Rank	Medium Rank

High ranked risks

Risk Register
CMS-doc-13480

Minimum Likely Maximum

RI-ID	Title	Probability	Schedule Impact	Cost Impact	P * Impact (k$)	P * Impact (months)
Risk Rank : 3 (High) (15)						
RU-402-1-01-D	PM - Foreign exchange rates are uncertain (DOE)	100 %	0 months	-6600 -- 1120 -- 9420 k$	1,313	0.0
RU-402-1-02-D	PM - Future escalation rates are uncertain (DOE)	100 %	0 months	-2220 -- 1250 -- 2980 k$	670	0.0
RU-402-2-01-D	OT - Uncertain performance of Hybrids vendor	100 %	0 -- 2 -- 12 months	0 -- 168 -- 648 k$	272	4.7
RT-402-8-01-D	ETL - Additional FE ASIC prototype cycle is required	40 %	4 -- 5 -- 6 months	500 -- 600 -- 700 k$	240	2.0
RT-402-1-05-D	PM - Significant funding delay during project execution (DOE)	21 %	0 -- 0 -- 9 months	0 -- 0 -- 3339 k$	234	0.6
RT-402-4-18-D	CE - Additional concentrator ASIC engineering (MPW) run is required	50 %	6 -- 7.5 -- 9 months	164 -- 241 -- 385 k$	132	3.8
RT-402-1-12-D	PM - Major import or export issue (DOE)	50 %	1 -- 2 -- 4 months	18 -- 136 -- 500 k$	109	1.2
RT-402-2-91-D	OT - Shortfall in Outer Tracker scientific labor	30 %	0 months	0 -- 0 -- 1049 k$	105	0.0
RT-402-4-01-D	CE - Additional FE ASIC engineering run required	25 %	8 months	336 k$	84	2.0
RT-402-8-30-D	BTL - Concentrator Card requires significant design changes	50 %	1 -- 3 -- 6 months	40 -- 135 -- 175 k$	58	1.7
RT-402-2-01-D	OT - Sensor quality problem during production	50 %	2 -- 3 -- 6 months	46 -- 79 -- 163 k$	48	1.8
RT-402-2-46-D	OT - Problem with carbon foam vendor	25 %	1 -- 6 -- 12 months	23 -- 158 -- 396 k$	48	1.6
RU-402-1-03-D	PM - Future Fermilab overhead rates are uncertain (DOE)	100 %	0 months	-1710 -- -30 -- 1820 k$	27	0.0
RT-402-8-07-D	BTL - Concentrator Card delay in external component deliveries	50 %	3 -- 6 -- 9 months	50 k$	25	3.0
RO-402-2-03-D	OT - Module assembly can be automated	66 %	-2 months	-500 k$	-330	-1.3

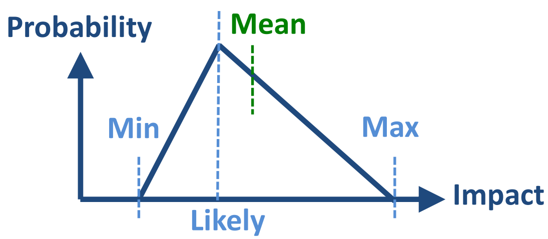
- Standing army and escalation burn rate costs are included in risk cost impacts – proportional to risk delays CMS-doc-13481

Risk and Contingency Analysis

- Build risk MC model using Oracle's *Primavera Risk Analysis*
  - Imports the P6 resource loaded schedule and risk register

For each iteration of the risk MC:

1. Risks do / don't happen according to their estimated probability
2. If a risk happens, choose cost and schedule impacts from p.d.f. e.g.



3. Re-compute entire schedule allowing for costs and delays of all risks

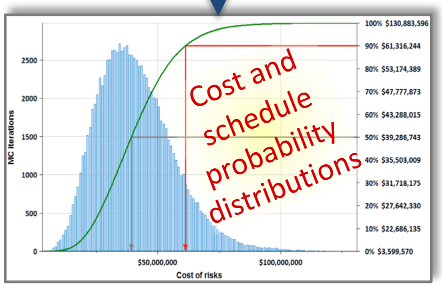
Repeat 1. – 3. for many scenarios

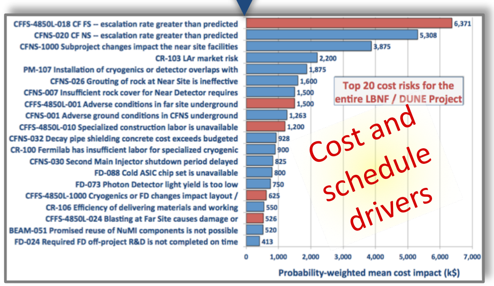
Probability distributions of project cost and finish dates → determination of **cost & schedule contingency**

P6 RLS
Activities
Schedule logic
Milestones
Fully burdened costs
Activity-level uncertainties

Risk Register
Risk description, owner,…
Risk probability
Impact: tech, cost, schedule
Standing army, escal'n burn
Mitigation &response plans

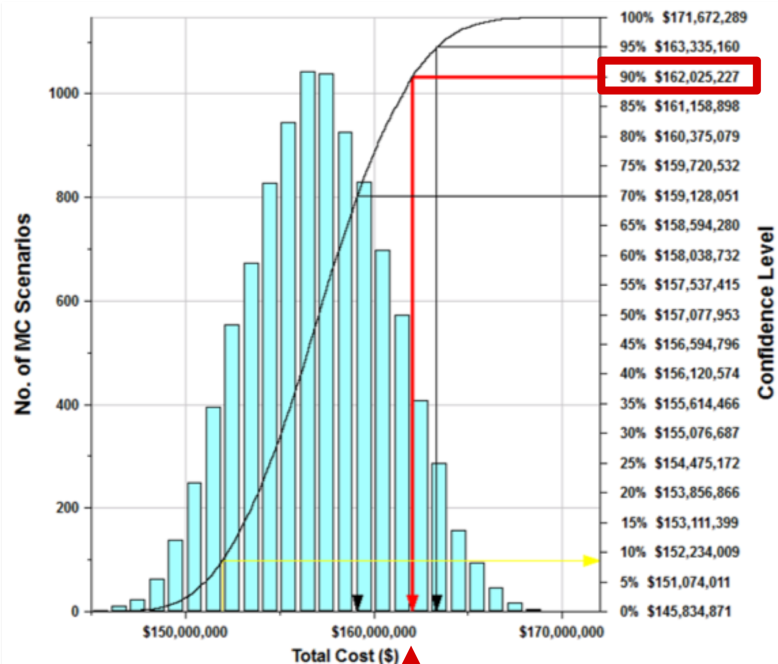
PRA Risk Model
Full resource-loaded schedule
Uncertain costs and durations
Probabilistic risk events
Cost & schedule impact PDFs
Correlations and burn rates





Total project cost

Results of risk MC with full P6 schedule and stochastic risk events

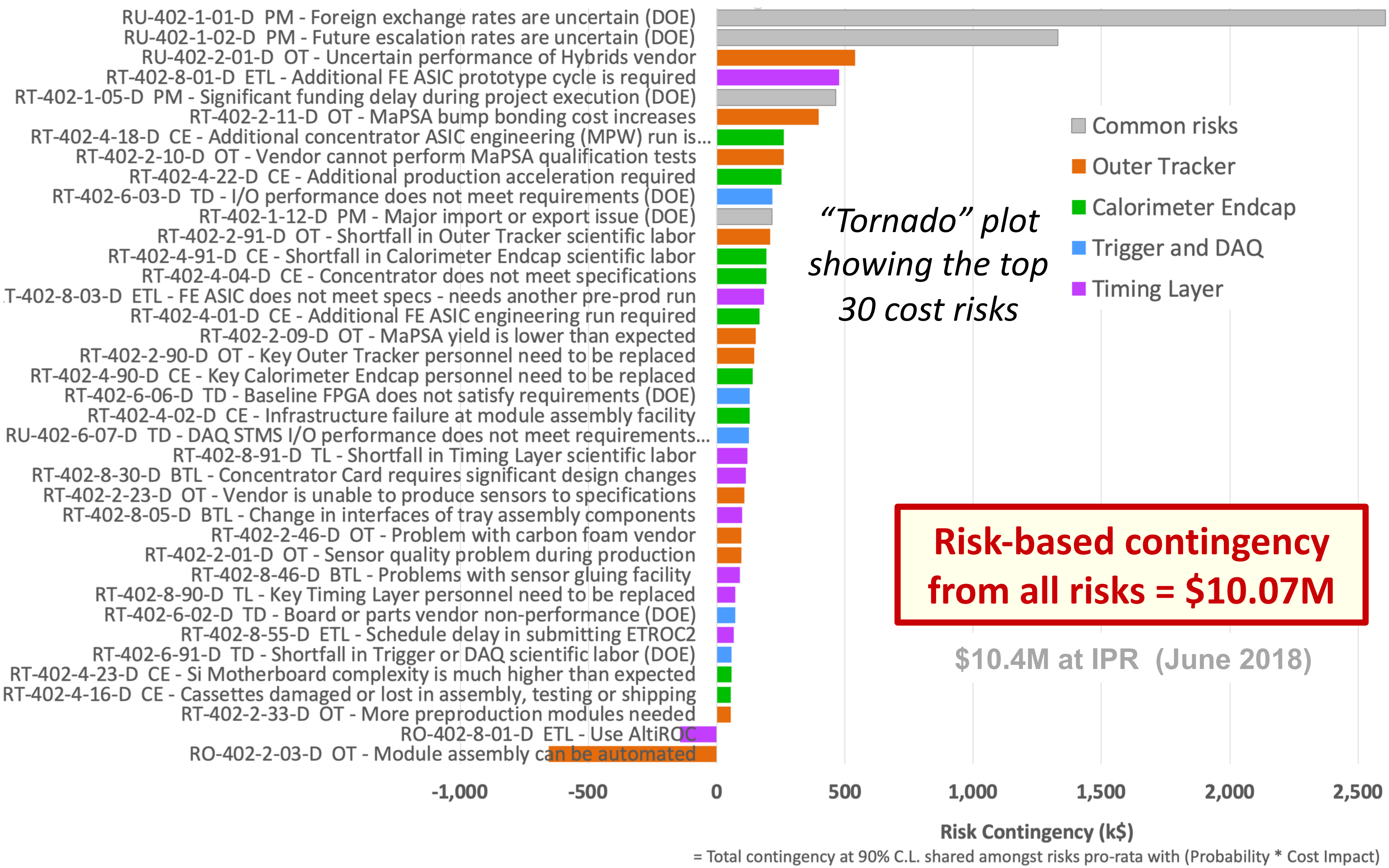


Analysis	
Iterations:	10000
Statistics	
Minimum:	$145,834,871
Maximum:	$171,672,289
Mean:	$157,123,818
Bar Width:	$1,000,000
Highlighters	
Deterministic ($151,950,672)	9%
70%	$159,128,051
90%	$162,025,227
95%	$163,335,160

Total Cost	=	**$ 162.03 M**	**(90% CL)**
-- Base Cost	=	**$ 124.63 M**	(cost to go = $106.52M)
-- Contingency	=	**$ 37.39 M**	(35.1% of cost to go)
– Est. uncertainty	=	$ 27.32 M	(25.6% of cost to go)
– Risk contingency	=	$ 10.07 M	(9.5% of cost to go)

DOE Guidance = $ 162.05 M

Risk-based contingency



CD-1 Cost Range

Charge #3

- For base cost + estimate uncertainty use AACEI / DOE* estimate classes
  - Mapped to Fermilab maturity categories
- For risk-based contingency, range is taken from the MC spread in risk cost
  - Lower (70% CL) to higher (95% CL)

ESTIMATE CLASS	*Primary Characteristic* DEGREE OF PROJECT DEFINITION Expressed as % of complete definition	*Secondary Characteristic* END USAGE Typical purpose of estimate	METHODOLOGY Typical estimating method	EXPECTED ACCURACY RANGE Typical variation in low and high ranges [a]
Class 5	0% to 2%	Concept screening	Capacity factored, parametric models, judgment, or analogy	L: -20% to -50% H: +30% to +100%
Class 4	1% to 15%	Study or feasibility	Equipment factored or parametric models	L: -15% to -30% H: +20% to +50%
Class 3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%
Class 2	30% to 70%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: -5% to -15% H: +5% to +20%
Class 1	70% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	L: -3% to -10% H: +3% to +15%

Notes: [a] The state of process technology and availability of applicable reference cost data affect the range markedly. The +/- value represents typical percentage variation of actual costs from the cost estimate after application of contingency (typically at a 50% level of confidence) for given scope.

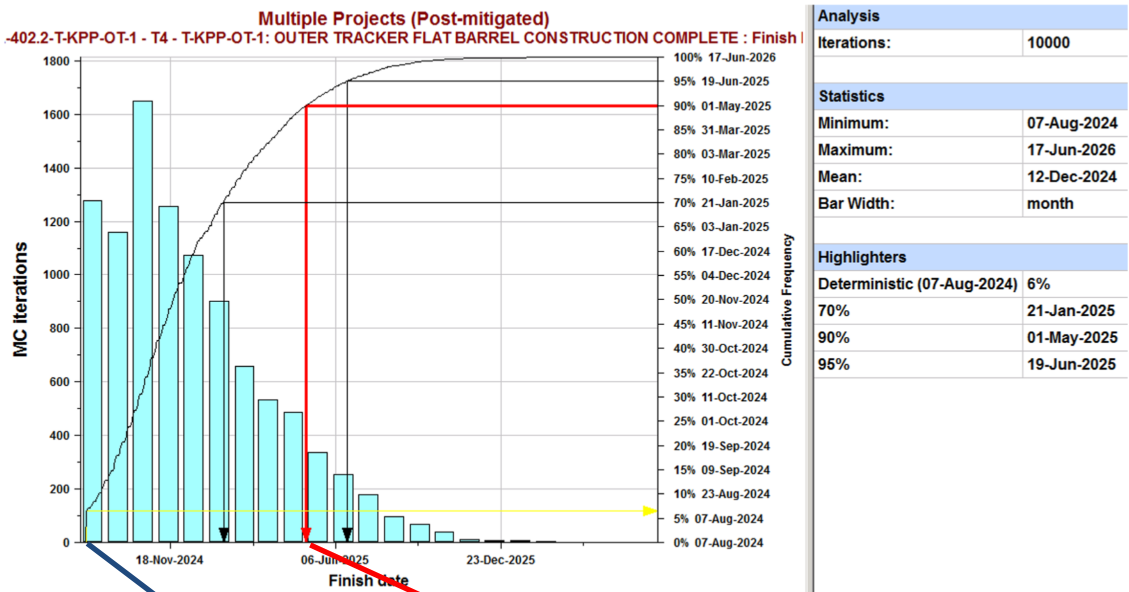
Component of cost estimate	AAECI / DOE Estimate Class*	Fermilab Estimate Class	Point estimate (M$)	Low range of cost estimate: Methodology*	Low range (M$)	Upper range of cost estimate: Methodology*	Upper range (M$)
Base cost + Estimate Uncertainty	Class 1	L1/M1 (Actual) L2/M2 (LoE)	47.09	-6.5% (AACEI: -3% to -10%)	44.0	9% (AACEI: +3% to +15%)	51.3
	Class 2	L3/M3 (Advanced) L4/M4 (Preliminary)	74.47	-10% (AACEI: -5% to -15%)	67.0	12.5% (AACEI: +5% to +20%)	83.8
	Class 3	L5/M5 (Conceptual)	30.39	-15% (AACEI: -10% to -20%)	25.8	20% (AACEI: +10% to +30%)	36.5
Risk-based contingency	90% C.L. from PRA risk MC		10.07	70% C.L. from PRA risk MC	7.2	95% C.L. from PRA risk MC	11.4
CD-1 point estimate of TPC			162.03	CD-1 lower cost range	144.1	CD-1 upper cost range	183.0

* AACEI: Association for the Advancement of Cost Engineering International. See: DOE G 413.3-21, Cost Estimating Guide, Section 4 and Appendix H.

Risk MC assessment of schedule contingency

- Risk MC aggregates delays stochastically in the full P6 schedule
- Risks will delay finish by **< 8.8 months** at 90% confidence level
- Plan has **11.4 months** of float before the CMS need by date
- T-KPP will finish before the need by date at 97% confidence level
- Will revisit schedule risk when new LHC schedule is known

Example: Outer Tracker – Flat Barrel construction



Results of schedule risk MC		Finish date (early)	CMS need by date	Float to CMS need by date (months)	Finish date (90% C.L.)	Delay due to risk (90% C.L.) (months)	Confidence level to finish before CMS need by date
T-KPP-OT-1	Outer Tracker Flat Barrel Construction Complete	7-Aug-2024	21-Jul-2025	**11.4**	1-May-2025	**8.8**	**97%**

Adequacy of schedule contingency

- In the baseline plan, L2/L3 areas have **(5.8–14.1) months** of float between the early finish and the CMS need by date
- Risk MC shows that risks will delay threshold KPP finish dates by **< (4.6 – 11.1) months** at 90% confidence level
- L2/L3 areas all finish before CMS need by dates at **> 93% CL**
  - Except Calorimeter Endcap which is 73% CL
- Will revisit schedule risk when new LHC schedule is known

Results of schedule risk MC		Finish date (early)	CMS need by date	Float to CMS need by date (months)	Finish date (90% C.L.)	Delay due to risk (90% C.L.) (months)	Confidence level to finish before CMS need by date
T-KPP-OT-1	Outer Tracker Flat Barrel Construction Complete	7-Aug-2024	21-Jul-2025	11.4	1-May-2025	8.8	97%
T-KPP-OT-2	Outer Module (9 Batches) Construction Complete	28-Aug-2024	20-Feb-2025	5.8	17-Jan-2025	4.7	94%
T-KPP-CE	Calorimeter Endcap Construction Complete	31-Jan-2024	29-Aug-2024	6.9	12-Dec-2024	10.4	73%
T-KPP-TD-1	Calorimeter Trigger Construction Complete	5-Jan-2024	1-Oct-2024	8.9	28-Aug-2024	7.8	94%
T-KPP-TD-2	Correlator Trigger Construction Complete	5-Jan-2024	1-Oct-2024	8.9	3-Sep-2024	8.0	93%
T-KPP-TL-B	Barrel Timing Layer Construction Complete	6-Mar-2023	1-Feb-2024	10.9	25-Jul-2023	4.6	99%
T-KPP-TL-E	Endcap Timing Layer Construction Complete	17-Apr-2024	19-Jun-2025	14.1	21-Mar-2025	11.1	97%

Note: float quantities from P6, PRA, and Excel may differ by ~0.1 months due to different treatment of calendars

Summary

Summary

Charge #3, #5, #7

- **M&S and labor costs** have been estimated bottom-up by experienced teams for all L2 areas – *including Timing Layer* – using vendor information, labor estimates, labor rates, indirect costs, escalation, exchange rates, and estimate uncertainties
- **Resource loaded schedule** has been developed in Primavera P6 and aligned with the CMS schedule – including schedule contingency to CMS need-by dates
- **Risk and MC-based contingency analysis** has been performed

Base cost = Direct + Indirect + Esc.	= $124.63M
Estimate uncertainty	= $ 27.32M
Risk-based contingency (90% C.L.)	= $ 10.07M
Total Project Cost	**= $162.03M**

Contingency = 35.1% of cost to go (40.2% including the scope options)

- **Cost, schedule, and risk documentation** is as required by DOE O413.3b
- **We are ready for CD-1 approval and are well on the way to a CD-2 baseline plan**, which will enable us to deliver the project with high confidence consistent with the CMS schedule and within the DOE cost guidance ($162.05M)

End

→ Supporting slides

HL-LHC US CMS

Risk Identification

Risk Register
CMS-doc-13480

Risk Breakdown Structure

+ 4 risks in multiple areas

Technical

ES&H 2 risks
Environmental, safety or health issues.

Requirements 6 risks
Requirements are poorly defined, incomplete, late or continually evolving. Requirements management process is inadequate.

Complexity 3 risks
Excessive design changes, assembly or commissioning problems. Workers inadequately trained.

Interfaces 2 risks
Design errors or omissions at interfaces within project or with external systems, inadequate systems engineering, assumed tolerances do not work in practice, scope missing at interfaces.

Technology
Technology is poorly understood, does not meet expectations, is not yet proven, or cannot be commissioned.

Quality 7 risks
Flaws or inconsistencies of design or manufacture. Pre-production (/production) quality is worse than prototype (/pre-production) quality. QA/QC process is inadequate or requires excessive time or resources..

Reliability / Performance 6 risks
Components perform worse after assembly or commissioning. Systems do not meet requirements due to unforeseen technical issues. As-built systems have commissioning issues.

Management

Planning 1 risk
Scope, cost, and schedule incomplete or does not match needs. Assumptions are incorrect. Schedule logic is incomplete or wrong. Planning for stakeholder communications, HR, risk, or procurement is inadequate.

Estimating
Cost or activity duration estimates are inaccurate, unrealistic, or do not reflect design maturity. Modeling of risks and associated cost and schedule contingency is inadequate.

Funding / Resources 10 risks
Funding is inadequate or mismatched to time profile of needs. Required personnel are not available to the Project. Labor disputes. Off project non-personnel resources not available.

Controlling 1 risk
Scope creep. Configuration is not well established and controlled. Excessive change control. Deficiencies in the system engineering.

Communications
Stakeholders not all identified. Communications needs not well defined or poorly executed. Cultural issues. Inadequate tools or processes to support project tracking, reporting and reviews.

Logistics 3 risks
Poor management of supply chains, within Project or external. Loss, damage or delays in transit. Customs and excise. Unforeseen storage needs. Unavailability of logistical resources (storage, transport, lowering equipment, etc.).

Experience / Capability 1 risk
Management, technical or other personnel lack required skills. Critical skills scarce on the market. Key technical capabilities are not available, within budget and schedule.

External

Collaborators 4 risks
Partners within the Project (e.g. Universities or Labs) fail to deliver. Problems with International partners (Agencies, Labs, Scientific Collaborations, Universities, Industry).

Facilities 8 risks
Expected facilities are unavailable or inadequate (e.g. test beam, laboratories, IT resources). Facilities are damaged or otherwise compromised (e.g. IT security violation).

Market 3 risks
Economic factors such as foreign currency exchange rates, escalation, or commodity prices (e.g. metals, energy, chemicals, construction materials and labor, etc.). Limited availability for specialist materials or items. Geopolitical shocks to specific markets.

Regulatory 1 risk
ES&H regulations. Construction permits and regulations. Financial compliance. IP. Import/export controls. Labor laws. IT security and personal data protection.

Vendors 15 risks
Inadequate planning of procurements. Limited choice of vendors for specialist materials or services. Scope change after contract placed. Cost increases on cost-reimbursable contract. Vendor production problems, delivery schedule, quality and disputes. Vendor problems or failure.

Public Impact
Inadequate consultation, communication and engagement with public stakeholders (local communities, general public, and local, state or national government). Failure to address concerns. Loss of reputation. Genuine or perceived risks to the community (e.g. environmental). Insufficient support for the science case.